VISIT…

Section XIV

Inspection and Failure Analysis

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Inspection and Failure Analysis

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Few municipalities, states, and certainly not the federal government, would ever consider letting a construction contract to a contractor without assigning the project to a government inspector to follow from beginning to end. Nor would private investors be willing to put money into any construction project that they knew had been built without continuing inspection by someone independent of the contractor or other financially interested party, to be sure that no shortcuts were taken, no inferior materials were used, nor incompetent cheap labor employed. It is always possible that an inspector can be bought, just as there are venal people in any business, but failure to inspect at all is obviously not in the best interest of the principal party.

Until the last fifteen years, most major chemical companies retained personnel just to follow up the construction work they contracted to be sure that the standards and specifications that were part of the contract were followed completely and without exception. In the last decade, however, boards of directors looking for places to save money and to reduce payrolls, have unwisely greatly reduced, or in some cases even eliminated, such jobs. The result is that today employees of the general contractor are usually assigned to inspect the work of their subcontractors–more often than not to follow specialty work such as "acid" resistant brickwork or monolithic surfacings, of which they have neither experience nor knowledge. In one instance, this writer observed an inspector at work who obviously had never before seen a quarry tile floor laid with acid-resistant resin joints installed in a kitchen. The only thing he seemed to understand in the specification was that the joints between the tile were to be ¼ in. wide. The specification writer obviously meant "nominal ¼" since,

unless the tile are ground, there cannot be an exactly uniform size joint due to dimensional tolerances of the tile. The inspector, however, treated this dimension as absolute. He did not bother to see that mixing instructions for the resin grout were followed, nor check to determine that the surface of the slab conformed to the specification, nor check the mixing of the adhesive bed, or the placement of the tile. Nor did he verify the uniformity of the top surface of the finished floor. The *only* thing he did do was to take out a steel rule and circle in white chalk as unacceptable any area where he found the joint to be not exactly ¼ in. wide–and this was more than half of the floor. Replacing this inspector and obtaining one who checked the important parts of the specifications was difficult due to his personal relationship with the project manager, but this was eventually done, and the work was accepted.

On another contract, in this case the principal was a university, all the inspection was to be handled by the general contractor, including that of the laying of "dairy brick" pavers. The specification was absolutely clear, including a requirement that the brick be laid in a furan resin bed a minimum of ⅛ in. thick, placed over a hot asphalt membrane. The finished floor was to have no greater variation in elevation between adjacent brick than 1/32 in. This was a tight specification, and one that would require slow and careful work to follow–but one that would assure a beautiful showplace floor.

When the bids were tabulated, it was noted that the low bidder–and he was too low–was under his competition by the exact cost of the ⅛ in. resin bed joint. Inasmuch as this bed was essential to accommodate the variations in thickness of the adjacent pavers if the floor was to be smooth, the architect was warned of the need for close inspection to be sure that the contractor did indeed install the ⅛ in. resin bed. The architect said that that was up to the contractor. His contract with the university did not include any site work. The contractor said that he did not intend to inspect the work in progress because that would cost him money. He trusted the subcontractor to do his job. If he did not, he would catch it on the final inspection.

The work was thus not inspected until completed in mid-August when the architect was advised that the floor was very rough (just as he had been warned that it would be). He telephoned the resin manufacturer to complain. The resin manufacturer pointed out that it was up to the contractor to deliver in accordance with specification. The architect said that the contractor stated no one could comply with that tight tolerance. The resin manufacturer said he could name ten firms who had no trouble meeting the specifications, and asked if the present contractor had taken exception to the specification when he bid. (He had not.) Then he was told the floor should be taken out and put it in correctly! The architect said there was not enough time to re-do the floor–the building had to be delivered by the time college opened–early September. (Of course, this was what the contractor counted on.) The contractor offered to grind the floor to make the surface smooth and meet specifications. The resin manufacturer warned the architect that grinding takes off the hard-burned surface, exposing softer interior. These brick will wear faster than the rest of the floor, and will have a different color. The result will be short life and early replacement of the floor.

Because he was unwilling to deliver the building late, the architect approved

the grinding. The contractor thus was able, by this change in the specifications, to save the difference between $6600 that the furan resin bed, ⅛ in. thick, would have cost him and $750 that grinding the floor cost him, so that he was able to come out with a good profit. The floor had to be replaced three years later–well after the usual one-year warranty expired. This type of sharp practice is quite common, and only careful inspection can prevent it. The principal who relies on others to do his inspecting for him is taking a chance.

If the contractor plans to cut corners or to evade the correction of errors, he will often try to keep working quickly over and beyond the error, hoping to proceed far beyond the substandard work. It would then be buried so deeply that to correct it could be very costly in time and material, and so delay the job completion that the client would let it go rather than tear out everything to get to it. This procedure usually works *unless* the inspector is given the authority to shut the job down as soon as he sees a violation of the specifications, and to keep it shut down until the substandard work is removed and the matter corrected. Such authority, therefore, should be given to the inspector. If the contractor disagrees with the inspector, he can appeal the decision before making the correction, but there will be less lost time and material than if he continues to work before making the correction and if the customer insists on the correction being made. If the inspector has this authority, the customer will not be under pressure to let it go, rather than take out sufficient material to reach the substandard work. Further, if the contractor is told that the inspector *has* this authority, he will be more careful in his construction work.

INSPECTION

Preliminaries

The procedure of inspection for the end user, as it applies to chemically-resistant masonry, starts with the drawings and specifications as received from the designers. The very first thing for the end user to remember is that anyone–any designer–can make mistakes, and under Murphy's Law, someone probably will, whether it be on the drawings or in the specifications. Therefore, the user should do the following.

(1) Examine the drawings first, then carefully read the specifications to see whether *as prepared* the details and the specifications will produce the end product that is desired. Is everything absolutely clear? Can anything be interpreted in more than one way? Can there be any misunderstanding? If there is, mark that item for clarification.

(2) Examine the drawings and read the specifications a second time carefully, keeping in mind all the design limitations and rules from the appropriate section of this book. Is there anything on drawings or in specifications that violate these rules or limitations–anything that cannot be done as described? If there is, mark that item for review.

(3) If any exceptions are found in (1) or (2), this is the time to correct them. Bring in the designer, go over the items with him, and make changes to resolve the matter, changes which both you and the designer can agree upon. Only *after* such matters are settled should the construction be put out for bids.

(4) It is important that you (if your company is the end user of the corrosion-resistant masonry equipment or structure) follow the construction carefully. If this is only a part of a larger contract, the general contractor will be expecting to follow this himself. Whether he does so or not, and whether or not he has handled such subcontractors before, you would be well advised to keep your finger on it yourself. Any contractor is more careful if he knows he is being observed. But the general contractor may have planned to make a profit on this subcontract by squeezing it–and only by following it carefully yourself can you be sure that there will be no shortcuts taken. If this is a separate contract, of course you will have an easier time following it.

Often, the general contractor will plan on installing all concrete substrates himself. To save some of his costs, he may plan to cut corners on the contouring of concrete walls (if these are specified), to provide rough slabs; ignoring the specifications for the concrete finish specified, or otherwise furnish a concrete that does not, as delivered by him to the subcontractor, meet the specifications as written, leaving it to be the subcontractor who is to install the membrane and brick, or tile, to provide any finish required to meet the specifications. It may not be possible for the subcontractor to make up such deficiencies, nor will the subcontractor have included in his costs this additional work. Consequently, he will be unable to do an acceptable job. The subcontractor will almost certainly have had his materials delivered to the site, ready to install when the concrete is finished. If he refuses to accept the concrete in such condition, he may be told by the general contractor that, if he does not agree to apply his materials and finish the work, the general contractor will terminate his subcontract, force him to remove his materials at his expense, and refuse to let him bid future work. Fearing to alienate the general contractor, he may reluctantly proceed. This author has, on several occasions, observed the unacceptable results of this situation. In all cases, he told the owner that the work was unacceptable, that all materials had to be removed, the concrete corrected, then new membrane, brick and tile re-laid. Failure to force this issue will result in both unsightly appearance and short life expectancy for the contruction. Of course, there will also be considerable delay on the completion of the contract.

It is, therefore, *vital* that the principal's inspector catch such improper acts as they occur, so that they can be corrected without excessive lost time. If *one* error is permitted to pass, others will follow.

(5) Before accepting any bid from any contractor, be sure that the contractor submits experience data, showing the satisfactory (to the customer) completion of at least three contracts of similar nature and involving the same or equivalent materials, within the last two years. In addition, he must guarantee that if awarded the contract, at the very least the lead craftsman to whom this job will be assigned will be the one who handled one or more of these reference jobs. If he is unable or unwilling to use craftsmen and supervisors experienced in this work, he should not be permitted to bid.

(6) Regardless of the outcome of the bidding on this subcontract (if such it is), demand to review the bids. Note any differences in the bids between those received and all exceptions taken by all bidders, whether or not these exceptions were taken by the lowest bidder. Is the low bidder close to the others? If he is much lower, examine the bid carefully to find out why. Has he included every-

thing? Is he planning on using alternate materials? Does he meet the experience clause? Has he included (a) weather protection at site? (b) Storage and handling costs for materials? (c) Heat in cold weather, ice or other cooling materials for hot weather? (d) Will he see that site and materials are protected over weekends, (at correct temperature) over holidays and at night? (e) Check out the references for past work carefully with the operators and maintenance people at site, *not* with Purchasing, for any comments they may wish to make about workmanship or materials. Only those *using* or *maintaining* the floors or equipment really know if everything is satisfactory. Don't let anyone sign up the low bidder just because he is cheaper. You may have cause to regret it. If you are overruled by Purchasing, put your disapproval in writing so that it is recorded.

(7) You can't be everywhere yourself. If you can't get your company to give you some help, talk to those working in the vicinity of the construction and tell them you will be grateful for their comments if they see something unusual going on. Tell the receiving desk to check in carefully everything brought in or shipped to the contractor, and note where all of it is being stored. Check his records every day and inspect the shipments. Examine all markings on packages and compare with the shipping documents and with the specifications to confirm that all materials are those named in the specifications. Examine the storage facilities to be sure that everything is kept clean and dry, and that perishable items–those with limited shelf life–are stored *exactly* in accordance with the manufacturer's recommendations, including storage temperatures. Check all equipment brought onto the site by the contractor to be certain that no specifically prohibited equipment (such as mops to apply asphalt membranes, serrated trowels to apply mortar bed under tile, motor-driven mixing equipment for mortars or monolithics with mixer speeds greater than 350 rpm) have been brought onto the site, and that the site is clean and *kept* clean and dry.

(8) Get the names of the *experienced* men whom the contractor has agreed to bring on the site, and be sure that they really worked on the project you have checked out. Contractors often shift men from one job to another. It is important that you check regularly to be sure that the experienced men are not taken from your site for other work until the contract is completed to your satisfaction.

(9) Before the work starts, sit down with the job foreman and go over the drawings and specifications with him. If the specifications cite manufacturers' literature and/or instructions, go over that too. Be sure that you and he are in absolute agreement about all aspects of the job. If you find any disagreement on the design, or how the materials are to be assembled, make sure that the foreman and you discuss the matter carefully with the designer to be absolutely sure what is wanted and to be fully in agreement. If you find disagreement on the installation or mixing procedures, get the materials manufacturer to send his technical representative to meet with you, both to settle the differences, and to be certain that what is done meets the specifications. Verify that adequate reinforcing has been designed with all concrete, and that the specifications cover the welding (continuous) and surface (free of all weld splatter, holes, protrusions, internal angles, etc.) of all steel that may require lining. Take minutes of the meeting covering all points discussed, get them typed up, and then signed "approved" or "agreed" by the contractor, the designer and the materials manufacturer to be certain that there is no misunderstanding.

(10) If the work is out-of-doors, make sure that if weather forecasts indicate rain, high winds or temperatures outside the acceptable range (60° to 85°F), (a) cover is provided to prevent rain from falling in the work area, (b) dikes or barriers are in place to prevent the intrusion of ground water, and well points provided, if appropriate, (c) wind breaks are in place, (d) shade is provided if temperatures are near 85°F or (e) heat is provided if temperatures are near 60°F, (f) check all materials to be certain that they have been stored *for 48 hours prior to installation* in the acceptable thermal range–the higher range in cold weather, the lower in hot, (g) check and record the temperature of the substrate in several areas. It is *substrate* temperature, not air temperature, that is the limiting factor. Check the humidity to determine the dew point. No installation can be permitted when air temperatures fall within 5°F of the dew point. Some manufacturers may indicate an acceptable working range as low as 50°F. Exept for materials that cure at 35°F, do not accept this low a temperature for material storage. If something should happen to the heating system and the temperature drops below 50°F, you are left with no safety allowance and work will have to be stopped not only until heat is restored, but until *all* materials have been brought back to the minimum surface temperature–probably 48 hours. (h) If there is any possibility that there is water in or under the substrate, test the substrate by the mat test (see under *Design*) to be sure that it is dry.

Concrete

If new concrete is to be installed, go to the bulk plant where the mix is to be loaded, taking with you the formula for the mix, and verify it–not with the plant superintendent, but with the workman at the chute who is loading the truck. If there is *anything* in the mix that he is loading–air entrainment agent, water reducer, additive of any kind, that is *not* in the approved formula that was ordered, *stop* the shipment *now* and order the truck to be emptied, and stay with the workmen until you are satisfied that the mix is *exactly* as ordered. Don't let anyone tell you that an additive in the mix that is in addition to what is called for in the formula will "improve" it. It can have exactly the opposite effect.

When the concrete gets to the site, before it is placed, demand to see a slump test. If it is greater than 4 in., unless a higher slump is specifically approved by the materials manufacturer, stop the job and tell the contractor to remove the concrete from the site as unacceptable.

After the concrete has been placed, be sure that the finishing and the curing procedures *exactly* follow the designer's instructions, and that the full curing time specified is permitted. At the conclusion of the specified curing time the mat test for moisture (cited above) should be run, at the locations last poured or where you feel there is the greatest likelihood of finding dampness. If a monolithic topping is to be applied at this time, you should also run compressive strength tests with a Schmidt (or Swiss) Hammer and a bond tensile test (Elcometer) using as the adhesive for the coupons the monolithic that is to be applied. The bond must register 300 psi minimum, and the coupon must pull concrete (including aggregate) over the entire surface of the coupon.

It is customary for the concrete strength to be verified by making cylinder samples at each day's pour of concrete, from the same mix used in placing the

new concrete. These cylinder molds are poured at the same time that the concrete is placed. Be sure that such samples are made from each truckload used, and poured at the identical time that the rest of the load is placed. See that these molds are placed in a warm and secure spot where they will not be bumped or otherwise disturbed for at least 24 hours and at the same temperature as that of the recently placed concrete. Do not allow anyone to remove the samples before the concrete at the site is hard and can support traffic. If jolted or subjected to conditions different from that of the placed concrete, you cannot expect tests run on these samples to be representative of the concrete that has been placed.

If the concrete is to be formed–a vessel, pit, trench, etc.–make sure that if release agents are to be used on the forms, they are ones that are acceptable to the membrane manufacturer and installer. Verify that bracing is firm and strong so that the weight of the concrete, as it is poured, will not move or deflect the forms, and that forms fit neatly and the formed surface will be uniform and smooth.

Observe the pours to assure that the concrete is adequately, but not excessively, vibrated to produce uniformity and freedom from voids, honeycombing and air pockets. When wet to wet pours cannot be made, make sure that continuous water stops are placed and that before the next pour is made, the preceding hardened surface is coated *within* the proper time limit with an acceptable concrete bonding agent.

When the forms are stripped, make sure that all surface laitance and form marks are removed. All the wires must be cut back well below the concrete surface. Check and sound the surface for holidays, honeycombing and stone pockets, breaking surface crusts open to expose any that may be hidden under a thin skin. These (and the wire holes) must all be hand-filled (packed) carefully with a stiff and strong sand/cement mix and packed tightly. Over troweling is not permitted. This brings laitance to the top and creates a weak surface.

All floor surfaces must be smooth and sloped enough so when flooded drain completely without any standing puddles. If they do not, they are unacceptable and the contractor should be required to cut out sufficient surface material in the low areas to install patches and bring the surface to uniformity with the surrounding area.

All tools used to finish the concrete must be clean. No release agents may be coated on the tools. (Release agents may wear off and leave remnants on the concrete surface, affecting the bond of membrane system.) And no sealing or curing agents may be used on the concrete surface that have not been accepted *in writing* by the manufacturer and installer of the membrane material. If oil or grease lubricants are found to have been used on the forms, the contact surfaces must be brush sandblasted to remove all traces of the lubricants.

Check carefully (especially close to the form bottoms) to be certain that the formed concrete is all dead straight or *uniformly* curved as specified. If there is even the slightest deviation from the design contour, that section must be cut out and ground smooth.

All concrete pits, vessels and deep trenches should be checked for water tightness. This is done by (1) plugging all outlets, (2) filling to the top with water, and allowing to stand, covered, for no less than 48 hours. (3) After at least 48 hours, add water to replace any loss by evaporation or soaking into

the concrete. (4) At a marked point, measure the depth accurately, take the temperature of the water and cover tightly. (5) After 24 hours, uncover and measure depth and temperature at the mark. Adjust depth for any difference in temperature (coefficient of expansion of water and thermal change). If the level is more than 1 in. lower, there is a leak somewhere that must be located and stopped before the vessel can be lined.

Prior to application of membrane or monolithic check to be sure the concrete is sufficiently dry, by applying a rubber or plastic mat or sheet flatly to the concrete surface, taping the edges. After 24 hours, if any moisture collects under the mat, the concrete is too damp and must be dried.

Brick

Of all the materials brought to the site for the contract, brick are the most likely to vary in quality. The specification will have identified them by type and, if they are "acid brick," by ASTM Specifications, most probably C279, which classifies them primarily by fluid absorption and loss in weight in an acid boil test. The manufacturer is expected to ensure uniformity in physical and chemical properties, and that they are within dimensional tolerances by testing random samples taken in accordance with ASTM C67, and he should certifiy that these tests have been run, and that the brick shipped comply with the specifications. However, if this is a large contract involving large numbers of brick, it is still advisable for the inspector to visit the manufacturers' plant and inspect the facilities, the brick and the records, and observe at least some of the sampling and testing. It should be noted that although the specification is quite clear on the limits of acceptable physical and chemical properties of all brick furnished, the dimensional tolerances indicated apply only within each individual shipment, so if there are a number of shipments required to complete the order, it will be up to the end customer and his inspector to assure acceptable overall dimensional tolerances for the duration of the contract.

Unless the inspector monitors the brick shipments carefully, it is entirely possible that at least some shipments will be made in inclement weather, in open body trucks, and without cover, so that brick arriving wet and/or in dirty condition may not be noted. Even on tightly strapped stacked pallets, this author has found brick in the center of the pallet coated with road dirt. While the brick, if they otherwise meet the specifications, are acceptable, they should not be taken to the job site and used until they have been cleaned and dried. It is most important that the inspector also monitor the storage area, make sure that it is covered, and, in cold weather, heated, and that all pallets are stored off ground, at high enough elevation so that they will remain dry and free of surface water should there be heavy rains and surface flooding. All brick in each shipment should be stored together so as to reduce any problem that may result from dimensional variations.

At least 48 hours before use, all pallets must be broken down, and the brick stacked in open checker fashion in a space that is *maintained at a temperature in the range of 60° to 85°F.* If there is dirt on the brick inside the pallets, they must be removed, cleaned and restacked in open checker manner 48 hours before use so that they can dry and come up to temperature.

Mortars

Some mortars are heat sensitive. The speed of set of furan mortars in particular, is much accelerated by heat, so that "open time" can be reduced to 10 minutes at 85° to 90°F. The effects of temperature on setting speeds of other resins are less extreme, but the contractor will have more time to use up his mix at a 60° to 70°F material temperature. Phenolic mortars must be stored prior to use at temperatures of 60°F or lower. If they are left in areas where they may be overheated, they can be ruined in a short time or so badly affected as to be unusable. There is a case on record of phenolic mortars being delivered to a site in Texas late on Friday, and left on the loading dock, resulting in materials which were totally unusable by 7 A.M. on Monday morning when the construction crew arrived. On the other hand, no serious damage will result if the components of resin mortars are subjected to temperatures below freezing.

Silicate mortars, however, will not be injured by storage in warm locations, with the possible exception of a few with limited shelf life, where it is possible that shelf life may be shortened. But if the liquid component (sodium or potassium silicate) is frozen, the fluid mixture (a colloid) will "break" and the silicate will come out of solution and coat itself on the inside of the metal containers. If this happens, the mortar will not function until the silicate is redissolved–mixed back with solutions using a power-stirring device such as a "Lightning Mixer."

The liquid component of a *silica* mortar, if frozen, can never be reclaimed and must be discarded.

A sulfur mortar, which is normally shipped in blocks or chips, is unaffected by atmospheric thermal changes from below freezing up to 110°F or higher. Nor is it subject to water damage from weather or flooding, so long as it is dried off before putting the mortar in the melting pots.

Epoxy mortars, although susceptible to damage from water, are not seriously affected by thermal effects in the ambient upper ranges, and as long as the materials are kept covered, little difficulty is usually experienced.

Polyesters and vinyl esters are the most water-sensitive of all the resin mortars. Although they are somewhat affected by higher ambient temperatures, they can usually be installed without too much trouble even in the 90° to 100°F range. However, if water gets into the mix or comes in contact with resin, powder or mortar before setting takes place, the cure may well be permanently inhibited, and the mortar will probably have to be removed and discarded. There is a case on record of a shipment of carbon-filled polyester floor surfacing material which failed to cure, although the control sample retained at the factory was perfectly normal. After a lengthy investigation, it was found that the powder bags had been punctured–*small* holes–by the forklift operator. The air was close to 100% humidity and the carbon filler had absorbed moisture from it–enough to add 10% to its weight–although the powder appeared to be completely dry to the touch. After replacement of this powder, the mortar set perfectly.

From the above summary, the inspector should see the importance of determining the condition of all containers shipped onto the site, and that the storage conditions–completely dry, off the ground, ventilated, and in the correct temperature range–have been met by the contractor.

It may be a requirement in a chimney lining contract that mortar samples be taken at regular, perhaps unannounced, intervals and 1 in. by 1 in. right cylinder test units be made for compressive strength determination under the provisions of ASTM C579 to verify the quality of the mortar mix. If such a provision appears in the specification, it is important that the mortar be packed in the sample molds at the same time that the mix is carried to the masons who are installing the brick, and that the molds be placed on a shelf in a cabinet in the base of the stack, or in an enclosed space or room as close to it as possible, under identical conditions of temperature and humidity, and permitted to cure there for the exact period of time specified both before demolding and after demolding. At the exact expiration of the aging time specified, the sample cylinders should be taken to the testing machine and tested *at that time.* (They may NOT be tested at the convenience of the laboratory technicians at some other time. The test is meaningless and the results can not be correlated if the time span between the mix and testing and the environmental exposure are not identical for all samples tested.) The inspector must, therefore, make provisions for verification, and for the elimination of all variables.

Membranes and Expansion Joint Materials

Sheet membrane linings are usually shipped in rolls. Exceptions include plasticized-unplasticized vinyl laminates, specially compounded asphalt and asphalt and rubber compounded sheets, usually shipped flat in cartons or boxes. These are applied to properly prepared surfaces with an adhesive that may be air-cured or heat-cured. At all events, so far as storage is concerned, temperatures above freezing and under 100°F are usually not matters of concern, unless the manufacturer or applicator so advises. Water and dirt, however, damage these materials so they should be stored in a clean storage area, off the ground and under cover.

Fluid-applied membranes require similar storage, and unless the manufacturer advises to the contrary, the component materials may be stored in the same manner and under the same conditions as the sheet materials. However, all latex emulsions, and some few other materials, can be damaged by freezing, and it is unlikely that such damaged material can be reconstituted at the site. In any case, if freezing occurs, the manufacturer should be notified on the chance that he may want the material returned rather than discarded.

Examine carefully all liquid components received, and the shipping documents, and if delivered in cold weather in open body trucks, especially if they were more than a very short time en route, check the contents for freezing. The manufacturers should also be advised of any packages damaged in transit, requesting advice as to use or disposition.

INSTALLATION

No work should be started until you are assured of the following.

(1) All materials have now been brought to the site. Each item has been checked and double checked to be certain that it is (1) the *exact*

material specified or an approved (by the designer) equal, (2) that it is clean, dry, free of any contamination, and in the specified thermal range, and (3) that the packages are undamaged, no seals broken.

(2) All surfaces to be coated/protected meet prescribed surface preparation requirements, including finish, and are clean, dry, in the correct thermal range, and sloped in accordance with the specifications.

(3) The contractor's crew at the site includes the experienced and trained individuals, whose names have been given to you.

(4) No proscribed tools or equipment are on site.

(5) Cover, weather and wind protection should be as specified and in place. If a spill occurs or water intrudes, all work should be stopped until the area is once more clean and dry.

Membrane

If the substrate is concrete, the most frequently employed membrane is hot asphalt.

(1) Observe the application of the primer. This must be *scrubbed* on using a stiff bristle brush or broom. It may *not* be sprayed, or applied with a paint roller or a soft paint brush, nor poured on and allowed to puddle. If the color fades as it dries, so that the concrete surface merely looks dirty, another application must be made, until the surface remains completely black.

(2) While the primer is being applied, the asphalt kettle is set up. Make sure the kettle is empty, dry and clean. If this is a roofing kettle, be sure that any remnants of asphalt have been scraped out of it *before* the kettle is heated and before any asphalt membrane material is put into it.

The cover (if detached) should be placed next to it in case of need. The heat should be brought up slowly to prevent smoking and foaming. Observe the opening of the containers, removal of container exteriors and the loading to be sure that no foreign matter enters the kettle with the asphalt. The hot asphalt pouring (using) range must be within the thermal limits given by the supplier of the materials. Before application is permitted, be sure that the liquid in the kettle is smooth, thin, and free from foaming, bubbles and excessive smoking.

The contractor should have a man assigned to stay with the kettle to keep it stirred, to fill the containers in which melted materials are carried to site, to keep the heat adjusted so as to maintain the contents in the proper pouring range, to keep the kettle full, recharging it as required, and to prevent anyone from taking liquid out of it as long as there remains unmelted material in it. He should prevent smoking in the vicinity of the kettle and, should the contents catch fire, close the cover at once, or if it is detached, put it in place and seal off any air leaks around the edges of the cover with wet burlap sacking. Under *no* circumstances should anyone be allowed to turn a fire hose on it or to use chemical fire extinguishers on it.

During breaks and lunch, someone should remain with the kettle *at all times*, stirring it occasionally, and making sure that it neither cools off nor overheats. At the end of the day, the heat source is removed and the kettle is covered. The following day, the first one on the job will be the kettle man since it will take an hour or more to get it ready to use.

(3) Application may start only *after* all solvent has evaporated out of the primer, but the surface is still clean and tacky.

(4) Application of the hot asphalt on a floor (or other horizontal flat surface) is by pouring the material on the surface and spreading it with a squeegee—usually wood, and approximately 18 in. long. Observe workmanship carefully to be certain the mechanic is providing a glassy, smooth and pinhole and bubble (or blister) free surface. If there are bubbles or blisters in the membrane, the job must be stopped until they have been removed and the membrane repaired. (See the section on Asphalt for procedure.)

(5) Application to walls or other vertical or irregular upright surfaces is made in the same manner, starting at the bottom and working from the bottom to the top. (See the section on Hot Asphalt for full instructions.)

(6) The reinforcing is applied *carefully* using a roller or some other means to flatten it out, remove all wrinkles, and press it into the asphalt already applied. Here is where one frequently finds carelessness. *Before* the fabric is applied, the asphalt layer should be a smooth, glossy, uniform $\frac{1}{8}$ in. thick, free of bare spots, holes or bubbles. The thickness should be verified using a mechanical thickness gauge, such as a large nail with distances marked on it from the point in $\frac{1}{8}$ in. increments. A piece of chalk should be carried to mark every point where the membrane has been punctured to verify the thickness. The mechanic's repair and sealing of these holes should be checked to be sure they are liquid-tight. In like manner, the thickness of each increment in the membrane should be verified.

If other types of membranes are used, and/or if surfaces other than concrete are to be membrane protected, read *carefully* the specifications and the manufacturer's literature on each and the section in this volume on that type, and verify surface preparation and thickness, uniformity and continuity of membrane. Make sure that not only the finished surface, but each intermediate one is free of dirt, blisters and voids. Where the substrate is metal, and the membrane is suitable for such testing, supervise spark testing to be sure that the voltage is adequate to provide liquid-tightness, but not so high as to burn holes in the membrane.

Monolithics

Troweled surfacing materials (monolithics) sometimes are used as membranes, where there may be a load on the surface beyond the capability of a membrane to support. In such cases, there may be adjacent areas of membrane and monolithic. If the system is to be continuous and void-free, the monolithic must be overlapped at all edges by the membrane, or the two surfaces continuously mated or flashed together. The inspector should examine this section very carefully for voids and discontinuities. In addition, he observes the following inspection procedure on the application:

(1) He checks the surface of the substrate carefully for proper surface preparation, and verifies the compressive strength with a Schmidt (Swiss) Hammer, and the surface bond strength with an Elcometer, using the monolithic material itself as the bonding agent for the coupons. If a primer is used, then use it in bonding the coupons. The Elcometer test run in this manner also verifies the compatibility of the concrete surface and the monolithic. To be considered

satisfactory, the coupon must pull concrete and bits of aggregate over the entire surface.

(2) Verify the proportions of the components in the mix to be sure they are those specified by the manufacturer, and measured *as specified* by weight, and that the mix is properly trowelable–neither too "soupy" nor too "stiff." Do *not* rely on or accept the assurances of the mechanics for this. Do not permit the addition of *any* unauthorized material to the mix. Verify that speed of all power mixers is not more than 350 rpm.

(3) Observe the application of the primer. All surfaces must be adequately covered, with no bare spots and free of puddling.

(4) The application should be uniform in thickness, smooth and compact, without "tears," cracks, blisters or holes. Any such irregularities should be removed and repaired while the material is still soft. At the end of the day, and before any work breaks, make sure that all ragged edges, etc., are removed, so that a clean, tight juncture of new to old can be accomplished when work is resumed.

(5) Watch the mortar pallets carefully to see that no material is used after it has passed its work life–become too stiff–and that any such material is discarded and not mixed into a subsequent batch.

(6) Verify that expansion joints are cut or formed over *all* points of movement in the substrate: expansion joints, control joints, cold seams, working cracks, etc.

Brickwork and Expansion Joint

(1) Before bricklaying starts, check the substrate (and/or membrane) and the brick as they are brought to site, for cleanliness. Verify with a *surface* thermometer that they are in the correct thermal range, and make sure everything is dry.

(2) Check the tools and the mortar box to be sure that they are clean and dry, and that no prohibited tools (such as serrated trowels) are brought on site.

(3) Observe the mortar being mixed. If a power mixer is used, make sure the mixer speed is under 350 rpm. Check the measurement *by weight* of the proportions and see that the person measuring the proportions marks the measuring containers correctly after weighing, so that future measurements can be by volume.

(4) Make sure that the mixing is carried to complete uniformity of the mortar. Observe the way mortar handles on the trowel. It should have sufficient body so that it clings and does not fall off when the trowel is turned so that its face is vertical.

(5) Observe the masons' "pallets" to be sure that all the mortar is smooth and creamy–free of lumps.

(6) Watch the way the masons handle the trowel and butter the brick. Are the mating surfaces *completely* and uniformly covered with mortar? (If the mortar is "runny," it can run out of the joints and should be discarded. "Dipping" brick into mortar is *absolutely* prohibited. If there are any voids or bare spots, more mortar must be applied.)

(7) Watch the brick being laid, pressed down onto the membrane or the brick below it, and slid into place next to the adjacent brick. Mortar should be extruded at all joints as the brick is pressed and tapped into place.

(8) The excess (extruded) mortar should be cut off with the trowel by the mason, leaving the surface smooth. If the joint is cut while the mortar is still within worklife, it will smear. This will not make any difference if a wall (or a chimney liner) is being built. However, if a floor is being laid and minimum smearing is desired, the mortar should be allowed to cure undisturbed until the worklife has elapsed (usually about $^{3}/_{4}$ hours) and then cut. The mortar will then be stiff enough to cut cleanly without smearing. Obviously the mortar so removed must be discarded, not reworked.

(9) Make sure that all brick cutting is done with a saw unless the designer has agreed to accept hammer-cut brick. The cutting must be done away from the installation to prevent dust and chips from getting into the work or the mortar mix. Make sure that all spaces are filled with single units–whole brick or squarely cut brick–not with chips or small pieces.

(10) Observe the layout of all expansion joints carefully to be certain that: (a) Only whole brick (or if cut brick, no brick of less than half the longest dimension) is used as a side of the expansion joint. If cut brick are needed, place them back a whole brick from the edge of the joint. (b) No mortar, pieces of brick, rubbish, or other hard material intrudes into the expansion joint. (c) The width and depth of the expansion joint are uniform for its full length and the sides perfectly straight. (d) The sides of the joints are smooth, truly vertical, and planar–that there are no ragged or sloping edges or broken corners. (e) The expansion joint terminates in another expansion joint, the outside of the structure, or a sliding plane, so that it is not immobilized.

(11) If you discover any violations of these guidelines–even the smallest violation–stop the work at once and do not permit it to proceed until the violation is corrected.

(12) Make sure the brickwork is undisturbed and kept in the proper thermal range until cure is complete. (See manufacturer's literature to determine necessary time interval.)

(13) If sulfur mortar is to be used, read the section in this book on sulfur mortar, noting carefully all warnings and instructions. Verify cleanliness and dryness of the melting pot and all handling equipment. See that all safety precautions are observed, that no work whatsoever is done if substrates, brick or other materials that may be in contact with the hot sulfur are wet. See that the pot is stirred thoroughly at least once every few minutes, and kept stirred and covered, with heat removed when not in use. Handle fires in the same manner as asphalt fires (above).

(14) Measure the width of expansion joints and the distances between them, and walk the area to be sure that all points of no movement are isolated by expansion joints–and placed midway between them. If any are omitted, are the wrong dimensions, in the wrong place, or terminate in an anchor so that they cannot function, have them corrected before permitting the work to proceed.

(15) Verify that all expansion joint materials brought to the site meet the specifications. Observe the installation and if there is any deviation from the manufacturer's instructions or the specifications, stop the work at once and remove all material that has been installed which does not meet the exact standards and specifications.

(16) In placing cellular material in the bottom of expansion joints, make

sure that it is slightly compressed as it is installed so that it presses firmly against the joint sides. If the joint is packed with loose fibers, make sure that the packing is loose enough to permit the joint to close 25 to 50% more, compressing the joint that much further. If it is packed too tightly, the joint cannot function.

(17) The sealant used to finish filling the joint should end flush with the surface. If there is any "overpour," it should be left until cured, then cut off with a razor blade, trimming it down to the plane of the floor surface. There should be no air bubbles, nor voids. If any appear, they should be opened up and repaired in the manner recommended by the manufacturer of the material.

(18) It is permissible to broadcast fine, clean silica sand, or small amounts of the powder component of the mortar over the surface of an asphalt membrane to prevent workmen's shoes from sticking to the membrane and tearing it. Do not allow other materials to be so used without the authority of the design engineer.

Final Inspection

After the work has been completed, spot checks should be made at intervals to make sure that the area and work are kept dry and clean, at the correct curing temperature, and free of traffic, until the cure is complete (see the manufacturer's literature for anticipated time interval).

Also check all curing areas (brick joints, monolithics, etc.) for the appearance of bubbles or blisters. An occasional blister is to be expected. If there are many, the matter should be brought at once to the attention of the designer for a decision on action to be taken.

After the third day, test all curing surfaces with the point of a trowel. If cure is delayed beyond the cure time shown in the literature, draw the matter to the attention of the designer.

Make sure that the contracting officer or purchasing agent does not make final payment on the contract until it is cleared by you.

FAILURE ANALYSIS

When a failure occurs in an alloy vessel containing chemicals, the owner starts to investigate to learn if the correct alloy was used, if the designer maldesigned it, or if the fabricator made some error in assembling it. However, when a failure occurs in an "acid brick"–or other chemically resistant masonry–structure, the customer often abandons the concept without investigation, with a comment such as "we *tried* it and it didn't work." There is *always* a reason for a failure and if you are able to analyze the failure so as to learn the source of the trouble, there is no reason why such failure cannot be prevented in the future.

Just as with the alloy vessel, failure may be initiated at any of three stages: design, selection and specification, and installation. When a failure occurs, *first* check the design. It is always possible that the design includes a detail that cannot be satisfactorily handled with chemically resistant masonry–that is a detail that should have been modified to make it suitable for these materials. Review the section on design to see whether all the factors mentioned there have been taken into account.

Next, check the service conditions. Has any change in the environment

occurred since the unit was designed? Is there a change in the maximum or minimum service temperature? When the unit is out of service, is it subject to below zero cold or desert heat, while the original design data included only *indoor ambient* temperatures when idle? Is there a change in the cleaning cycle? Has higher heat or live steam been used when only hot water was originally mentioned? Is a new or different cleaner or chemical being used? Has the process changed with different chemicals and thermal levels, or have either high pressures or vacuum conditions been introduced? Is the unit held at high pressures for extended periods, then dropped to atmospheric pressure in less than a second by opening a valve?

If there are any changes, whether those mentioned above or not, compare these changes with the resistance tables of the materials manufacturers, and study the section of this book on each material involved in the failure in order to confirm that the selection made is the correct or best one for all the conditions to which it is exposed.

Finally, consider the installation. If a competent inspector in your employ was present at installation, review his reports. Look for any violations of material selection, standards or installation techniques that he may have reported, even if the report states that they were corrected. If a wall has fallen down, check the supporting wall for bulges by using a string and/or straight edges. If lack of adhesion is noted between two components that should be bonded to each other, check the area of disbondment for foreign material–dust, dirt or water. Do not assume that nothing is there because you cannot see it. It may take a powerful glass or a chemical wash to find a contaminant. Do not assume that because you find a semisoft or a softened area of mortar, while all other areas are hard, that some chemical has damaged it. *Maybe* this is the case. But it is also possible that the mortar in that spot never hardened after it was installed. Perhaps the contractor did not mix his mortar thoroughly, and this small area was troweled with mortar containing too little hardening agent. Or perhaps this area was wet when installed or subject to drops of dew or water from another source after installation.

Some examples of such problems: a major manufacturer of spaghetti sauce installed a very large brick floor laid with furan resin mortar over an asphalt membrane during July. During installation, the weather was hot and the humidity was at 100%. The unit was completed on a Friday afternoon, the weather changed and the temperature dropped 15° to 20°F. The plant was closed for a week with only a watchman on duty, and all doors and windows were shut. By the time the plant reopened, the temperature was back in the 90's. Two weeks later, inspection of the floor showed that the mortar was somewhat rubbery on the surface, but had hardened at the bottom of the joint–a sure indication of surface water. A check with the watchman disclosed that during the cold snap, enough water had condensed on the walls to run down over the floor and puddle all over it. By the time the plant reopened, it was all dried up and so had not been noticed. The floor had to be taken out and relaid.

In a Houston plant, temperature-sensitive paint warned of overheating near the base of a CS_2 reactor which had only been in service for two months. After the packing was removed, a large number of voids were found in the silicate mortar joints in the insulating brick lining, many running all the way through to the shell. Under magnification, these voids were shown to be circular and almost

certainly the result of water which had flashed to steam—passing out through the brickwork, presumably when the unit was placed in service and heated up. Where did the water come from? A check of the plant personnel disclosed that the contractor had stacked the brick next to the vessel before and during the lining of the equipment. The brick were not covered, but were open to the weather. It was learned from the Weather Bureau that there was heavy rain during the construction period. Insulating brick have a high absorption. If wet brick had been used, the failure was explained. The contractor removed and replaced the lining with dry brick, and no further problems were experienced.

An experienced brick contractor obtained the order to install a brick lining inside a large waste collection tank—roughly 50 ft. x 20 ft. x 12 ft. deep—at an Army Ordnance plant. He completed the installation in mid-November, and the tank stood idle until the following March. When the operators prepared to put it into service, they discovered one long wall had fallen into the tank. The contractor asked for guidance from the manufacturer of the brick mortar. A technician was sent in. The technician, as instructed, snapped a string along the base of the wall and found that the concrete contractor had not braced the forms well enough, and the weight of the concrete, as it was poured, caused the wall to bulge inward at the bottom. After the bulge was chipped away and the concrete resurfaced, the brick was replaced and the problem was ended.

A waste collection pit of about the same size was built for a major oil company in the Houston area. The vessel was to contain a waste which might include various petroleum solvents, dilute acids and dilute alkalis. The consulting engineers designed it of concrete block cemented together, lined with a furan resin membrane reinforced with glass cloth, and then inner lined with two courses of acid brick and furan mortar. When the tank was completed, it was water-tested and found to have numerous leaks. The bricks were removed at those points; cracks in the membrane were repaired and the brick replaced. As soon as one repair was made, another leak started elsewhere. When the technical staff of the mortar manufacturer was consulted in a conference call including the contractor, the oil company project engineer and the engineering firm that designed the tank, the mortar manufacturer learned for the first time of the structural design of the vessel, and that (of course) it had not been tested liquid-tight before lining it. When the mortar manufacturer was asked how to make it tight, he told them that they were wasting their money. The vessel could never be made tight, because the walls would always move under load, and the membrane would rupture somewhere else. At first, they did not believe this, but several months—and many dollars—later, the vessel was abandoned. A replacement vessel was later built of sound, reinforced concrete, with the walls and bottom contoured, and a furan resin/glass fabric membrane installed in the manner described in this book, followed by two courses of brick and furan mortar. It has served satisfactorily for well over a decade.

In the late 1940s, a major chemical company designed a reaction vessel, about 3 ft. 6 in. in diameter and 16 ft. high, to handle a mixture of HCl and organic solvents. The process involved charging the unit, closing it, heating the process materials (with an internal heater) to 220°F, and at the same time building up pressure in the unit to 200 psi. The unit was to be held at that temperature and pressure for 3½ hours, then brought down to atmospheric temperature and pressure, emptied and recharged to make a new batch. This was one of the

first process vessels ever to receive a furan resin/glass fabric membrane, and it was inner-lined with 9 in. of the highest quality fireclay acid brick and furan mortar. The unit was in service only a month when the customer complained that the exposed surfaces of all the brick in the face course of the lining were being "eaten away" so that the mortar joints all stood out boldly–yielding a pattern resembling a waffle iron. The brick and mortar manufacturers both sent men down to examine the vessel. The brick technician stated that there had to be acid fluorides contaminating the process liquids as the only thing that could cause this damage. (The mortar had a carbon filler and so would not be damaged by acid fluorides.) However, chemical analysis proved this to be untrue. There were *no* fluorides, but the brick were certainly being destroyed from the face back, a little more brick loss with each batch. The technician from the mortar manufacturer stayed on to watch the unit being operated. All went as expected as the vessel was charged, heated, and the pressure brought up to 200 psi and held for 3½ hours. *But*, when it came time to bring it down to atmospheric conditions, the operator simply cut the valve open and the drop in pressure from 200 psi to atmospheric took place in a tiny fraction of a second–far faster than the brick, which were saturated and stabilized for hours at 200 psi, could relieve the pressure built up in them. This internal pressure trying to leave the dense brick so rapidly was causing the surface to spall off. The trouble was mechanical, not chemical. It was resolved by facing the existing lining with 2½ in. of carbon brick joined with the same furan mortar. The carbon brick was much more absorbent–porous–and it could bleed out the pressure more rapidly, while it acted as a buffer to protect the surface of the fireclay brick. Since that time, the same company has built many other, much larger process vessels of the same type–all with this inner 2 ½ in. of carbon brick to prevent the fireclay from spalling–and all functioning satisfactorily.

From these experiences, and many others like them, it is usually possible to track down and identify the sources of failures of chemically resistant masonry. Just as no alloy–no metallic structure–of any fixed design and composition–is suitable for all exposures, but will provide long and satisfactory life if properly employed, so will chemically resistant masonry.

If a failure occurs, analyze it carefully. Look *first* at the points covered above, and note any discrepancies in design, material selection and construction. Then look for any environmental changes, or perhaps the presence of something of which you were not previously informed. When you have completed this, turn to the following tabulations. Note which items of failure you observe. There may be several. Now read carefully the list of those causes that can lead to each observed problem. Make a list of everything on each list and underline those that appear on two or more lists.

Now carefully check out what you see against the underlined causes. There is a high probability that you will be able to identify the source or sources of the trouble and correct it.

First, let us consider constructions of masonry units (as acid brick) and mortar.

The following material is from "Spotting and avoiding problems with acid resistant brick." Reprinted by special permission from *Chemical Engineering*, May 3, 1982© 1982 by McGraw-Hill, Inc., New York.

The **boldface** numbers mean the following:

1 is noted where the cause of the failure can clearly be assigned to the designer.

2 indicates the fault is that of the applicator.

3 means there are two or more individuals who may be at fault.

4 indicates the materials manufacturer is responsible.

5 shows the fault probably lies with the operator.

I—Leaks through acid brick lining or floor. (Detected by "holing" of steel tank, or wet spots, discoloration, or collapse of concrete.)

1. Wrong mortar/membrane for chemicals and/or temperature. **(1)**
2. Wrong mortar/membrane substituted for that specified. **(2)**
3. Sheet membrane material had pinholes in it. **(4)**
4. Mortar/membrane materials were off-spec. **(4)**
5. Membrane applied improperly. **(2)**
6. Hot-asphalt membrane froze, then cracked, after application to concrete. **(3)**
7. Multicomponent membrane/mortar improperly proportioned or mixed. **(2)**
8. Mortar/membrane mixed with foreign material, such as wind-blown dust, or sand. **(2)**
9. Material applied after it passed beyond its worklife or outside of specified temperatures. **(2)**
10. Mortar/membrane not thick enough or in continuous layers; failure to install full-bed joints under or behind brick. **(2)**
11. Damage to membrane during bricklaying. **(2)**
12. Carbon brick and/or carbon-filled mortar in direct contact with lead or stainless steel caused holing of the lead or pitting of the steel. **(1)**
13. Concrete degraded. Anchors in the brickwork, or other penetrations through membrane into concrete, allowed flow of chemicals. **(3)**
14. If a vessel, it was not liquid-tight before being lined. **(2)**

II—Brick wall lining (rectangular tank, or gutter or trench) falls in. (Wall may or may not carry membrane with it.)

1. Brick lining too thin for height and width. Brick lining must be independent of substrate. **(1)**
2. Concrete wall may have inward bulge at some point. **(2)**
3. Failure to properly install expansion joints at correct locations, or failure to make them large enough. **(3)**
4. Use of improper joint filler, or improper installation of filler. **(3)**
5. Dirt or mortar in expansion joints, preventing functioning. **(2)**
6. See also I, nos. 3, 5, 9, 10 and 11.
7. Dirt or moisture on brick and/or membrane that prevented mortar from bonding properly. Or mortar improperly mixed and applied. **(2)**

III—Damage or loss of mortar joints.

Sulfur mortar:

1. Loss or crumbling can be due to overheating. Check recording thermometer, especially for cleaning cycles. Absolute top service temperature for sulfur is 203°F. Manufacturers say stay under 190°F. **(5)**
2. Empty joints due to poor installation procedures. **(2)**
3. Loss or damage can be caused by chemicals. Look for unnoted trace chemicals or cleaners. Perhaps operating conditions have been changed since design was done. **(1) (5)** (Heat damage usually leaves joint full, but crumbly. Chemical damage involving solvents usually removes some or all material from the joints.)

Resin mortar:

4. Receding or etched joints usually indicate chemical damage. **(1) (5)**
5. Joint damage can also result from putting brickwork into service before cure of the mortar is complete. **(2)** (Overheating may char or crack joint. It rarely shows up as joint loss.)

Silicate and silica mortar:

6. Soft, receding joints result from exposure to steam jets or to neutral or alkaline water. Receding joints can also be caused by HF or acid fluorides. **(1) (5)**
7. Neutral waters or washdowns, before cure was complete, caused loss of mortar. **(2)**

General:

8. Bricks dirty, so mortar did not stick to them and joints fell out. **(2)**
9. Mason never filled joint, laid brick dry. **(2)**
10. Mortar used past work-life, so had no adhesion. **(2)**
11. Unauthorized material mixed into mortar. **(2)**

IV—Damage to shale-fireclay brick in the lining.

1. Fairly uniform surface damage, etching or spalling is almost certainly chemical damage. **(1) (5)**
2. Acid fluorides dissolve off the brick face, leaving an etched surface. **(1) (5)**

   In either of these above exposures, carbon brick is the material of choice.
3. Spalling at edges of brick (at joints), but fairly sound at the middle of the brick. If joints recede **(1) (5)**, or were not full to start with **(2)**, expanding brick are not supported at edges, and corners spall off the brick edges.
4. Spalling of surface in selected areas. This can be due to:
   a. Local overheating from steam impingement. **(5)**
   b. Local exothermic reaction. **(5)**
   c. Use of soft (or underfired) brick. **(4)**

V—Sags or runs in mortar joints, usually accompanied by voids.

Soupy mortar is almost always the fault of the installer. **(2)**

Such joints can be identified by rounded, smooth, bulging horizontal joints in the brickwork, often glassy, accompanied by pinholes or voids near their tops.

VI—Heaving upward of brick floors and tank bottoms.

Floors:

1. Expansion joints improperly designed, in wrong places, or wrong size or wrong expansion-joint filler. **(1)** (See also II, 3, 4, 5.)

   [Rubbish in expansion joint prevents it from functioning. (added by author)]
2. Brick underfired or of a clay with excessive, irreversible growth. **(4)**
3. Failure to lay brick void-free. **(2)** (Air voids under

brick will pick up liquids, in which crystals can form, causing growth and upward pressure on brick.)
4. Voids or holes in the membrane permit corrosives to reach substrate. **(2)**
5. For epoxy adhesive bed, heaving is due to dirt, dust or faulty application. **(2)**

Tank bottoms (flat bottoms):
Items 1 through 4 apply.
6. Bottom flat, not ventilated, tank hot. **(1)**

VII—Cracking of brick linings of steel tanks.

1. Lining too thin to provide adequate insulation at the operating temperature. **(1)**
2. For lead sheet, or sheet elastomer or plastic, welds (or laps) not padded, brick not notched. **(2)**
3. Seizing of brickwork on seams causes cracking. (See I, 11.) **(2)**
4. "Jacking" of brickwork can cause cracks. **(2)**
5. Failure to provide for expansion at inlets, outlets and other shell penetrations. **(1)**
6. Cure shrinkage of mortar: Strongly bonding mortars, as they shrink on curing, can pull brickwork apart. **(1) (4)**

VIII—Voids in mortar joints.

1. Pinholes and other tiny holes in mortar joints result from air beaten in by a high-speed mixer in the mortar box. **(2)**
2. Pinholes and tiny voids result from insufficient mortar on the trowel. **(2)**

Now consider monolithic surfacings. (Although not identical, polymer concrete constructions will be found to be quite similar.)

The following material is from "Failure analysis of chemically resistant monolithic surfacings." Reprinted by special permission from *Chemical Engineering,* July 23, 1984 © by McGraw-Hill, Inc., New York.

I Failure to cure—material either remains soft or hardens only partially; alternatively, there may be both hard and soft spots

1. Moisture (e.g., rain, spillage) or other liquid has settled on the surface. This may be due to inadequate weather protection, flooding of the surface from one or more sides, cooling of the air below its dewpoint on the substrate, or cold-air drafts over the surface (from external doors, etc.).
2. Surface was wet or chemically contaminated when the surfacing was applied. Cause may be inadequate cleaning, drying or neutralization.
3. Concrete mix contained an admixture (such as an air-entrainment agent, water reducer or curing agent) that either reacted with and depleted the hardener in the surface material or inhibited the cure of the surfacing.
4. Concrete may have contained too much water (i.e., it did not dry enough), so that when the topping was applied, water collected under it to inhibit curing. (Thin sections may fail to cure completely.)
5. Resin and hardener were not mixed in correct proportions, or not mixed uniformly. (If cure is spotty, incomplete mixing is often the cause.)
6. Substrate or materials were too cold to cure properly, or the temperature of the substrate was allowed to fall below the curing temperature after its placement.
7. Overheating beyond their thermal limits will soften some monolithic toppings. If so, these toppings may appear to be partly cured, and show marks and indentations. They will usually re-harden when they are cooled. (See also Item II-11 and Item VI-3.)
8. The material was exposed to intense sunlight.

II Disbondment—material separates from the substrate or does not adhere

1. Surface was inadequately cleaned and dried. The bond is to dirt on the surface. (If dirt is on the surface, it can often be seen adhering to the underside of the delaminated surfacing material.)
2. For new concrete, the contractor may have used a curing agent or sealer that acted as a bond breaker.
3. For new concrete, cement finishers may have dipped trowels in, or wiped them with, a silicone cleaner.
4. See also Item I-4.
5. Where the day-to-night thermal gradient is ± 50°F, water under—not in—the slab may have been drawn up under the topping from as far as 15 ft down. If this happens, apply the monolithic on the 4 p.m. to midnight shift. The cure will be advanced enough to prevent such a problem by the time the temperature rises in the morning.
6. Oils, other release agents, or foams were used, and these left residues on concrete surfaces.
7. Concrete has inadequate surface strength. This can be the result of: (1) inadequate design specifications; (2) failure of the bulk plant to follow design instructions; (3) too much water in the mix; (4) excessive troweling in finishing the concrete; (5) failure to clean the surface or remove "laitance" (fine particles of lime or portland cement that come to the surface upon finishing). The surface of the concrete may be cleaned by brush blasting or by etching with hydrochloric acid. Proper design strength calls for a compressive strength of 3,000 psi at the time of application and a bond strength of 300 psi, using the specified surfacing material as a bonding agent.
8. Either the resin and the hardener were mixed to incorrect proportions or mixing was incomplete.
9. Substrate was too cold for adequate cure, but air temperature was high enough to cure surface.
10. Materials were used that were partly set.
11. Top temperature was exceeded. Topping has a higher coefficient of expansion than does the concrete. When the bond strength is exceeded, the topping will disbond, bulge, then crack. Cleaning by boiling water or steam can produce this. (See also, Item I-7 and Item VI-3.)

III Cracking

1. Topping was applied over an expansion joint, construction joint, or other point of movement in the substrate. (An expansion joint in the topping is required in such areas.)
2. The distance between expansion joints or stress-relief joints was too great. (Cure shrinkage results in accumulation of stresses in the topping. When these exceed the bond strength, the topping disbonds and cracks.)
3. For larger sections of concrete substrate, stress-relief joints were not placed at 20-ft or smaller intervals. (See comment under No. 2.)

4. Materials were improperly proportioned or incompletely mixed.
5. Materials were applied after working life had expired.
6. Note that if disbonding occurs, cracking due to stresses from cure shrinkage will almost certainly follow.
7. If overheating happens, disbondment will take place. If the topping is hard and does not soften appreciably at higher temperatures, it will crack.
8. Area had been frozen at particularly low temperatures. The material becomes more brittle and develops excessive shrinkage stresses at very low temperatures.
9. During cure, materials were exposed to intense sunlight—this is especially seen in spotty areas.

IV Penetration

All resinous, siliceous or sulfur cements, toppings and monolithics are porous to some degree. Diffusion through these surfacings is faster for small molecules. Expect eventual penetration in continuously wet conditions (e.g., puddling, retaining sumps and trenches in continual use). All areas surfaced with such cements, toppings and monolithics should be sloped to prevent puddling.

Penetration will result successively in: (1) disbondment if the penetrant is a chemical that attacks the substrate at all rapidly; (2) cracking of the topping; and (3) curling upward of the edges of the crack. After disbondment and cracking occur, the substrate will show signs of chemical attack. To verify this, peel off an adjacent topping that appears sound, and check the substrate's surface with pH paper.

V Chemical attack

Evidence of chemical attack can be: (1) surface softening; (2) surface discoloration that cannot be removed by cleaning; and (3) surface etching, by either destruction or removal of the aggregate (e.g., silica aggregate removed by HF exposure). For etching, the surface can remain hard and porous or become powdery and crumbly. Discoloration is followed by deterioration. Other signs are softening and swelling.

VI Blisters or bubbles

Part A. Appearing after application and while the material is still soft and before it has hardened. Bubbles or blisters are small; some may break, leaving small indentations

1. Materials have been mixed with a high-speed mixer, entrapping air in the resin. After the surface has been troweled in place and finished, air bleeds out as blisters or tiny bubbles. A paddle mixer moving at more than 350 rpm can cause this.
2. A breeze over 10 mph can cause this.
3. A highly alkaline surface (pH > 10) can result in "gassing" and subsequent blisters.
4. Application on porous concrete: Air in the pores expands as the daytime temperature rises, and pushes through the topping, resulting in blisters. This can be avoided by applying the monolithic after 4 p.m.
5. Application over concrete that has moisture in it or below it. The effect is the same as in No. 4, but here the underside of the topping also fails to cure properly. (See also Item II-5.)
6. Exposure to varying intense sunlight, heat or cold during installation and cure.

Part B. Appearing weeks after cure has taken place. Bubbles or blisters are thick-skinned and usually rather large

1. Possible diffusion of corrosives through topping attacked the substrate at the bond surface and caused gassing or concrete "growth," with resulting delamination.
2. Possible chemical attack from underneath. Corrosives may have entered the substrate elsewhere and traveled along the rebars.
3. Overheating may have caused disbonding and bulging, similiar to blistering, if the topping softened when overheated. (See also Item II-2 and Item I-7.)

VII Expansion joint failure

1. Loss of bond to sides of joint. This can be due to: (1) poor design—edges of joint were not at right angles to the surface; (2) sealant bonded to bottom of joint—joint opened and material was dragged off its sides; (3) sides of joint were dirty or specified primer was not used when joint was filled; (4) low-level chemical attack occurred—usually caused by a solvent; (5) elastic limit of the sealant was exceeded; (6) sealant was heated beyond its thermal limit; (7) subfreezing of the surface took place; and (8) material suffered thermal shock, resulting in too-rapid movement of adjacent surfaces.
2. Swelling of joint. The causes can be: (1) chemical attack, which results in swelling or gassing—this is detectable by presence of crumbling, a porous condition, or spongy cavitation and loss of strength; and (2) failure to use a compatible material under the sealant—as joint closed, noncompressible material below it extruded upward, pushing the sealant out of the joint.
3. Breakup of joint filler, usually due to either (1) excessive movement beyond the elastic limits of the sealant, (2) chemical attack, or (3) excess hardener in mix.
4. Brittleness, hardness, crumbling and loss of elasticity, due to (1) chemical attack or (2) overheating beyond the maximum service temperature.
5. Uneven cure. This is usually due to (1) exposure to moisture during cure, but can also be due to (2) wind blowing over the surface, (3) excessive sunlight, or (4) nonuniform mixing of the ingredients.

Procedures for failure analysis of expansion joints will be found in "Expansion joints for chemically resistant masonry," by this author, in *Chemical Engineering*, August 19, 1985, vol 92, no. 17, pages 79-81.

Figure 52-1: Acid brick lining in throat of a scrubber in a large power plant. Smeared surface is an immediate indication to the inspector that the mason has covered up voids and pinholes in the joints.

Figure 52-2: A pinhole still visible in the lining. A thin wire was inserted 4 inches into this hole. The inspector demanded removal of the lining, which, as expected, proved to be full of voids, with as much as $\frac{1}{8}$ inch of the backs of some of the brick bare.

Figure 52-3: More unacceptable workmanship. Dirty, sloppy workmanship, irregular joints in brickwork and expansion joints.

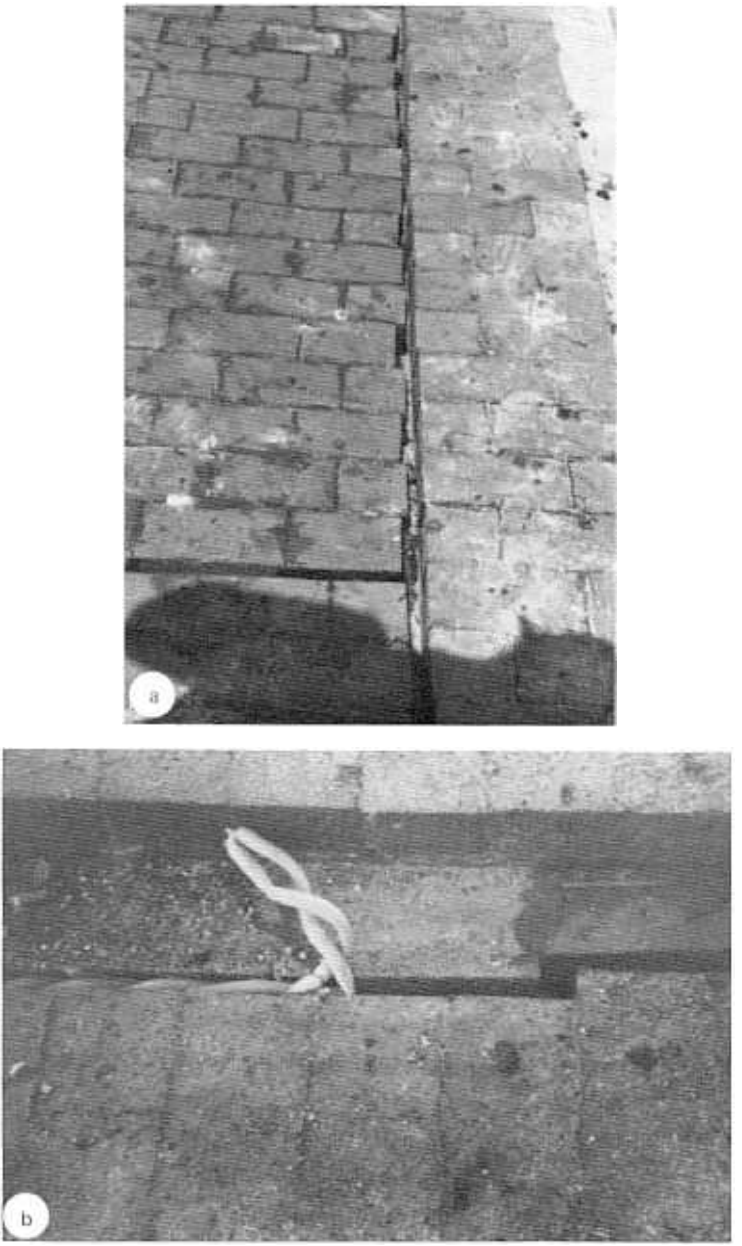

Figure 52-4: Note the unacceptable variation in the width of expansion joints and poor selection and placement of joint filler.

Figure 52-5: Note badly laid brick, irregular width of expansion joint, rough surface of membrane, and apparently flooded asphalt surface instead of surface smoothed with squeegee.

Figure 52-6: Note rough surface. Blisters indicate either wet surface or water in the substrate, drawn up by the heat of the hot asphalt. The interior of the kettle may have been wet, or rain water may have fallen into the kettle before or while the kettle was being heated.

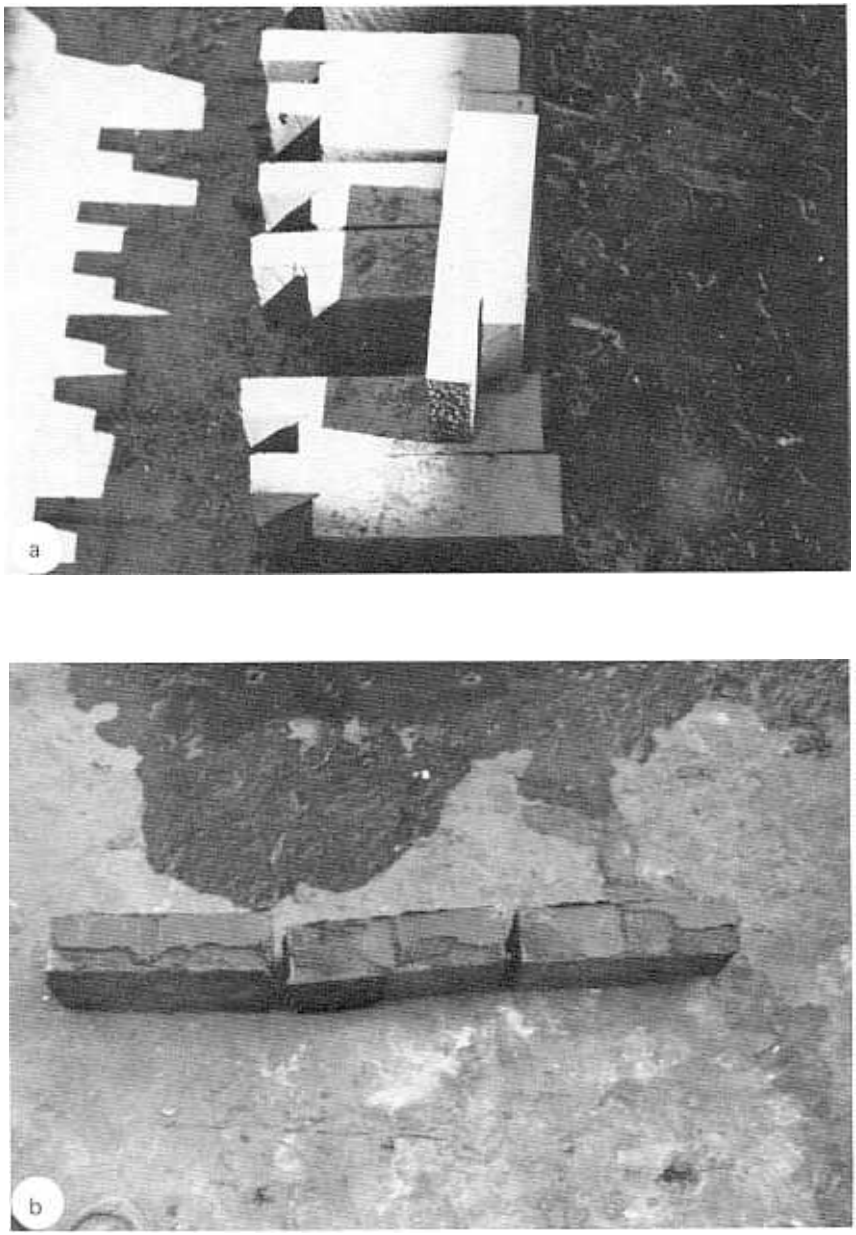

Figure 52-7: Careless, incompetent brick cutting and inadequate mortaring of bed joints under the brick. Note the sloppy finished surface.

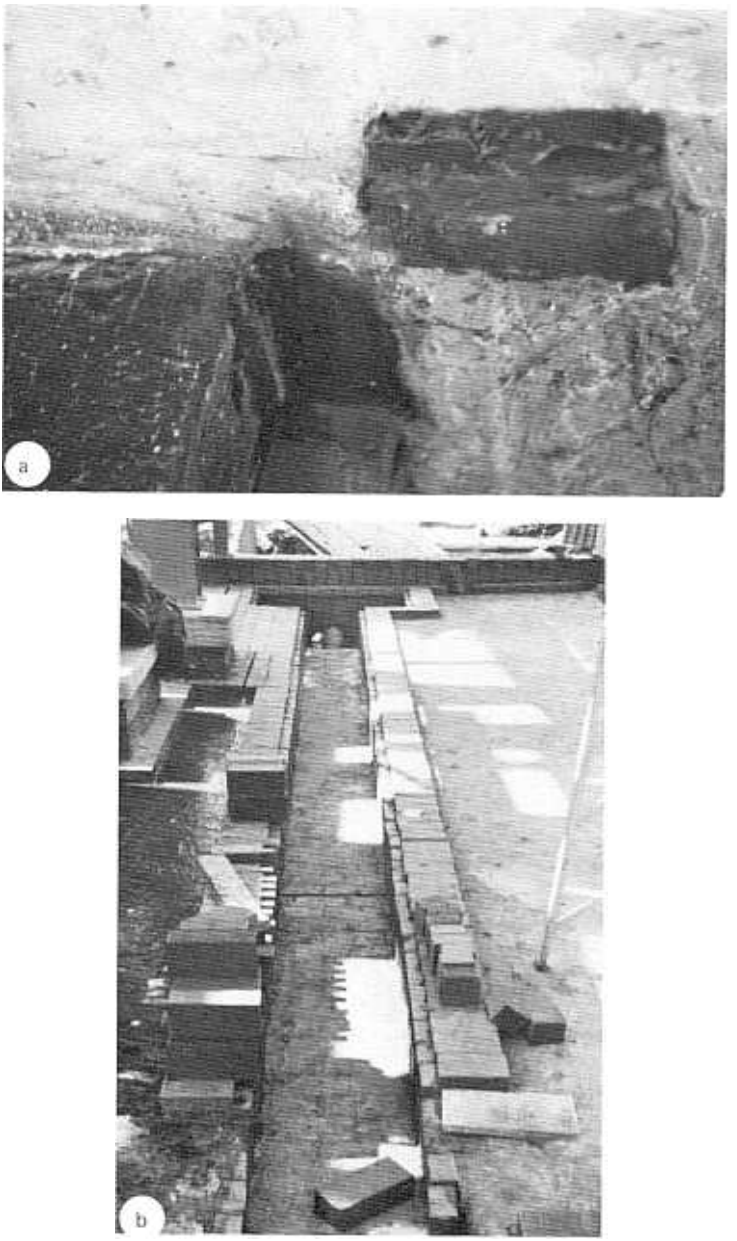

Figure 52-8: Brick surface not fully covered with mortar will result in voids in the bed and the joint. Note roughness of the surface. Membranes should be applied smoothly. Brick lines and cutting of brick should be absolutely straight.

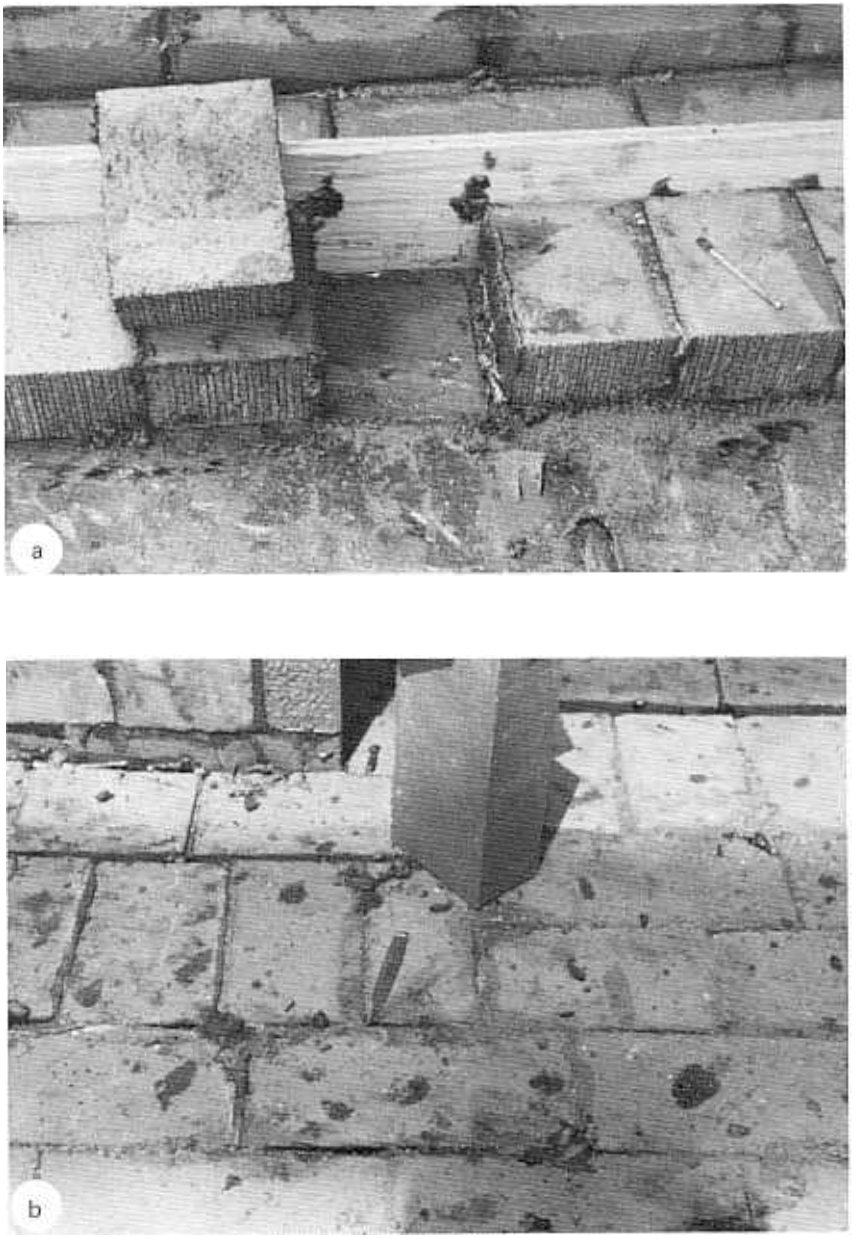

Figure 52-9: Sloppy, unacceptable brickwork with open voids. There is insufficient mortar in the bed joint, and the bottom of the brick are not fully covered.

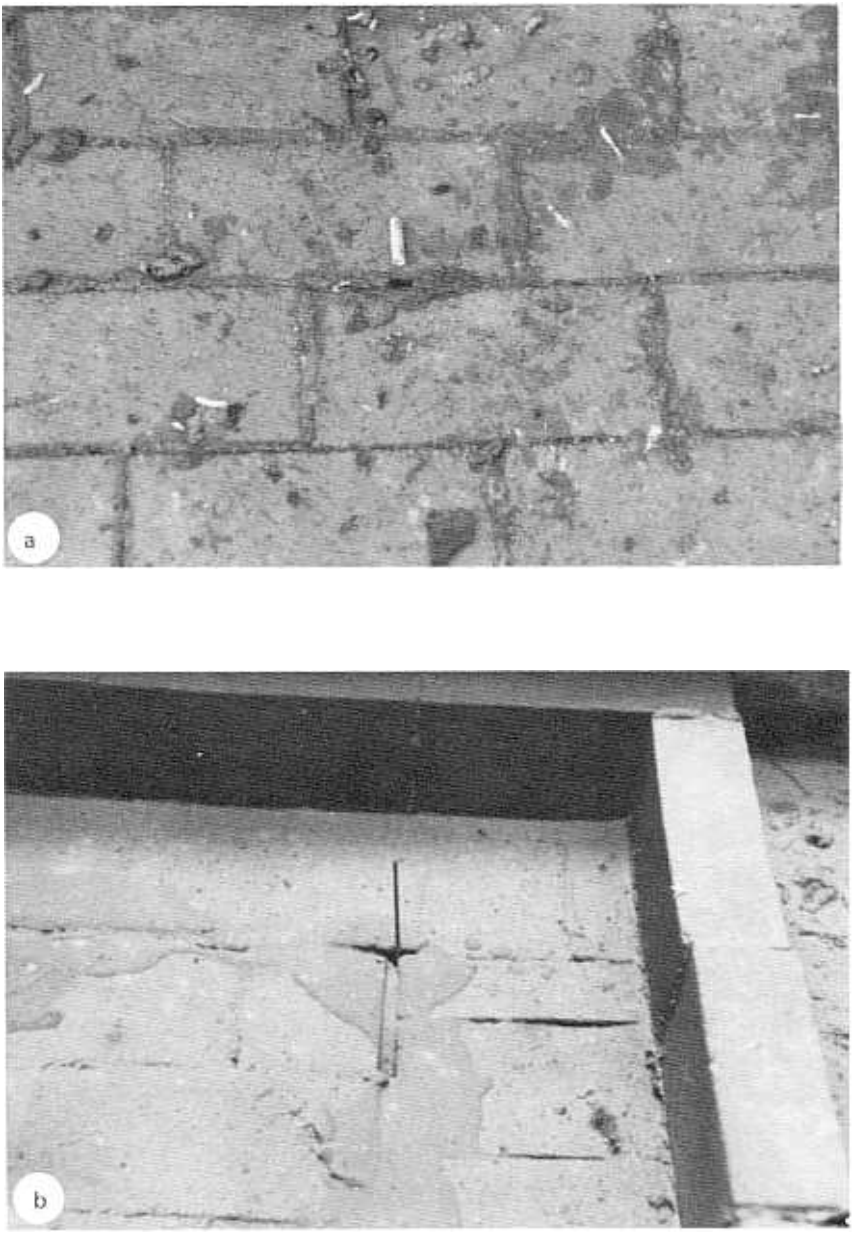

Figure 52-10: Examples of totally incompetent and unacceptable brickwork. Note dirt, voids and even an open joint in the curb, lower right corner of (b).

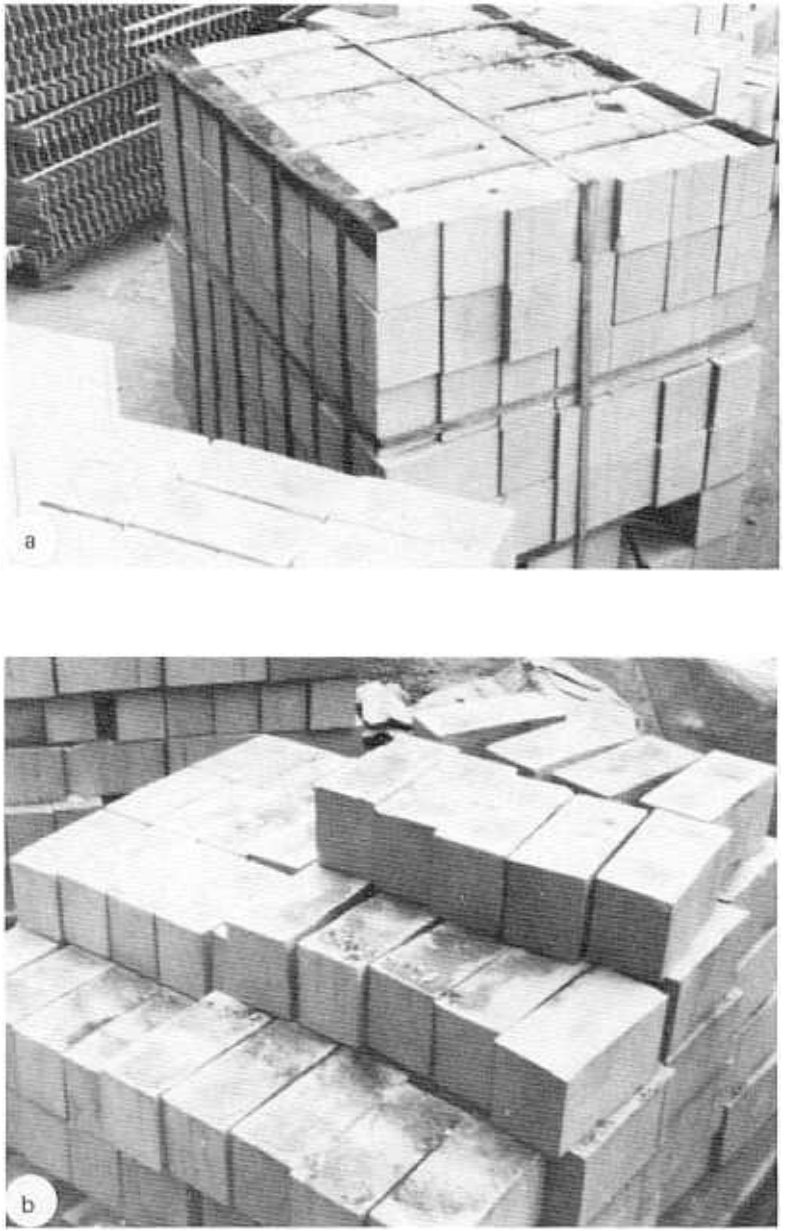

Figure 52-11: Acid brick shipped in an open-bodied truck in bad weather picks up a great deal of road dirt, which can get all the way to the center of the pallet. These brick must be washed and dried before use if the work is to be satisfactory.

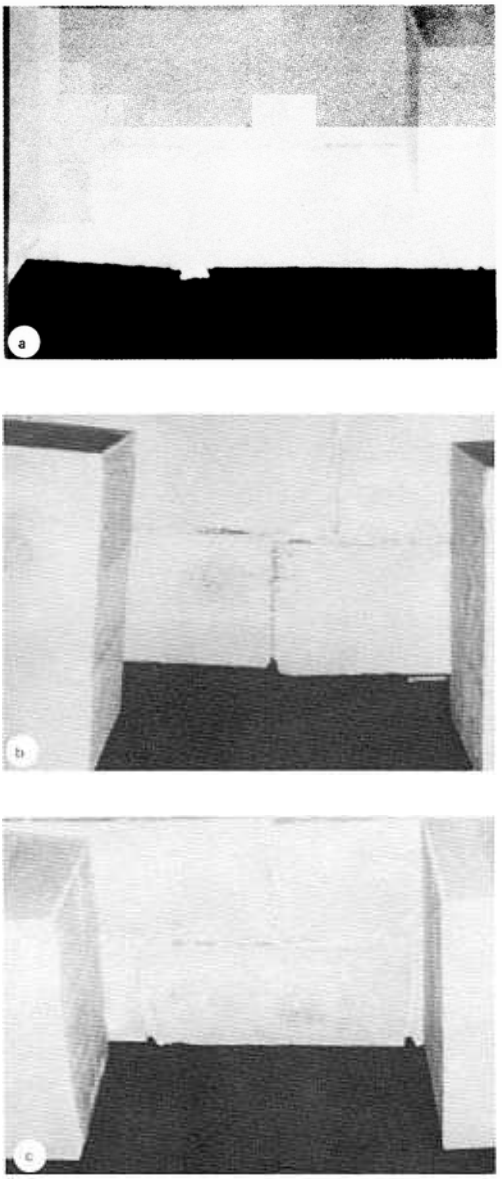

Figure 52-12: Three different work areas, same day and time, on a platform at the 780 foot level of a brick lining in a chimney, showing the surface of the work at the end of the shift by three different masons. All three left voids in joints, used too little mortar, and did not sufficiently cover the brick surface. Note shadows in center circumferential joint where mortar has subsided into a void below.

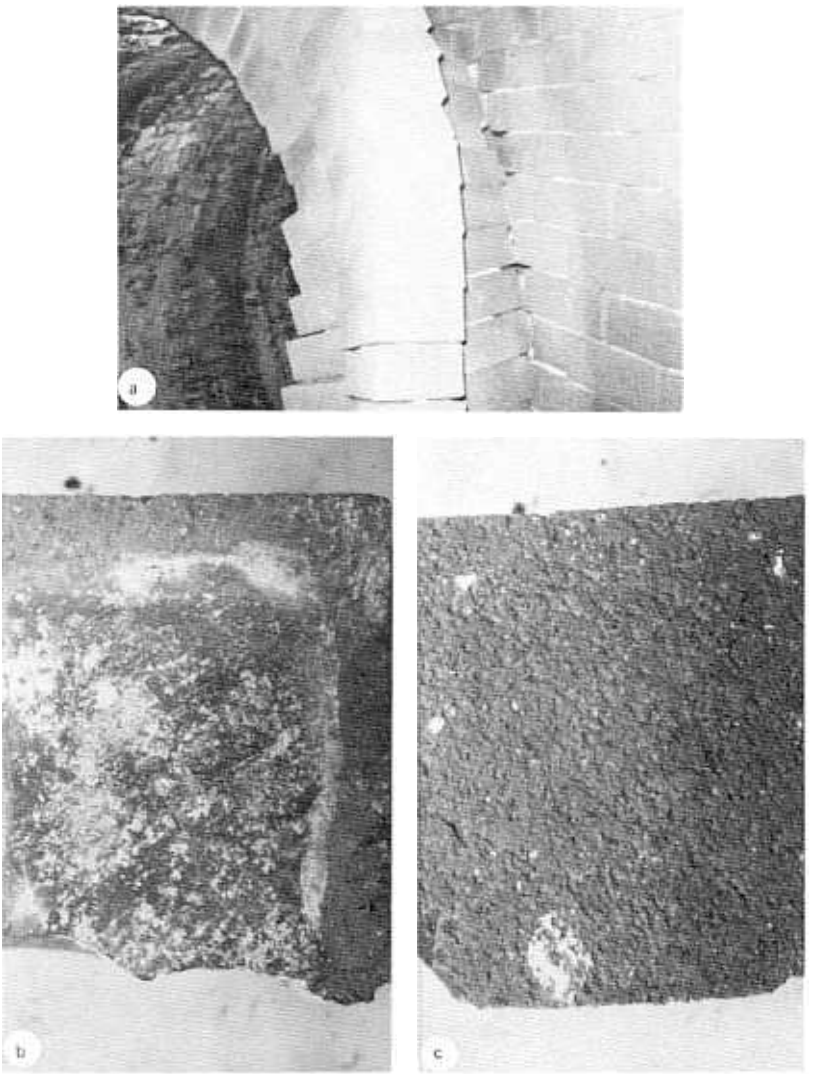

Figure 52-13: Showing the effect of trace amounts of acid fluorides in the acid washing the inside of the tower; in this case, 750 parts per million. This damage occurred in less than 6 months. (a) Top picture shows loss of silicate mortar. (b) Underside of a brick on the floor. Center of the picture displays original texture of the surface (protected by mortar). (c) Right-hand picture shows surface exposed to scrubbing liquid containing the fluorides.

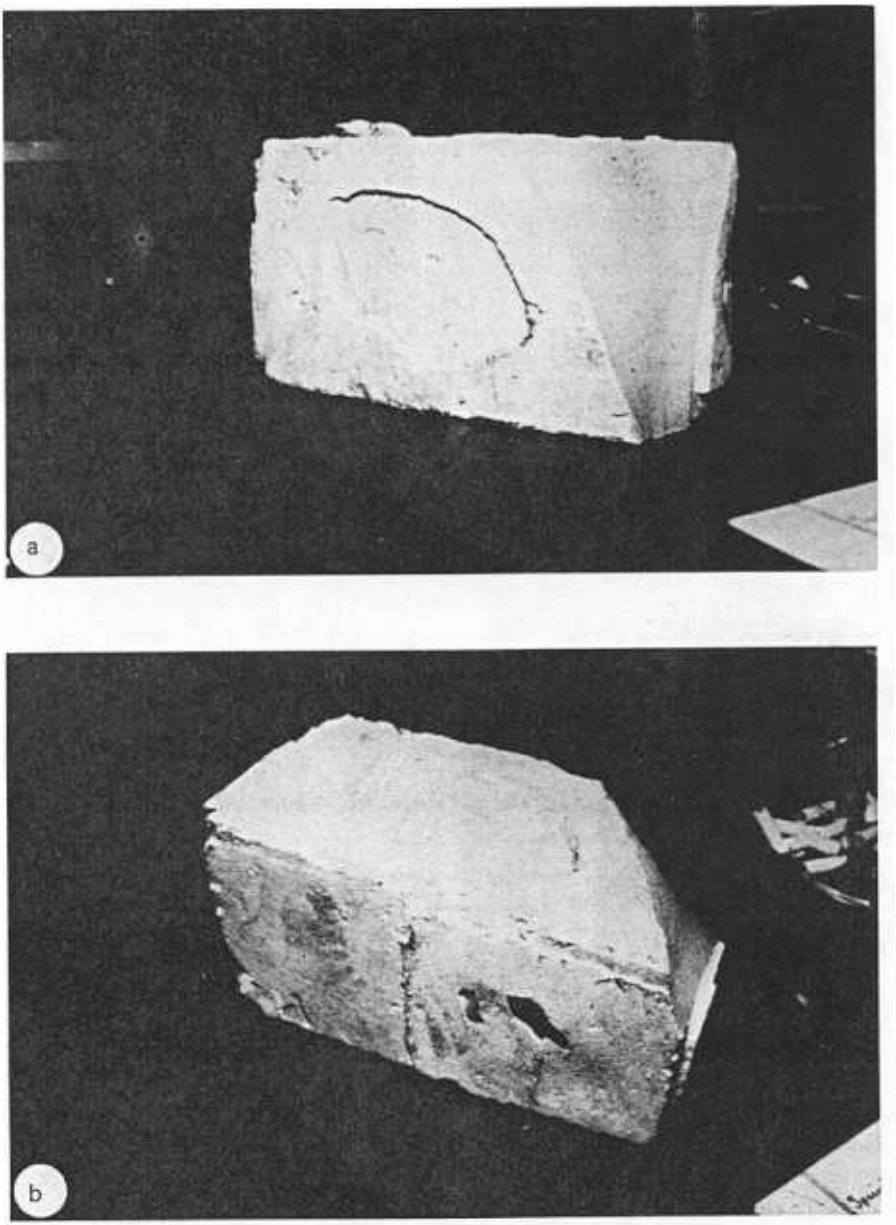

Figure 52-14: A brick removed from the top 8 feet of the brick lining of a chimney erected only 1½ years before. Note the clean separation of the mortar from the adjacent brick and the air voids in the joint, showing that the masons had applied the mortar to the brick either close to the end of its work life (too dry to wet the surface, or to wet brick, to which it would not bond), and that they used too little mortar to fill the joint.

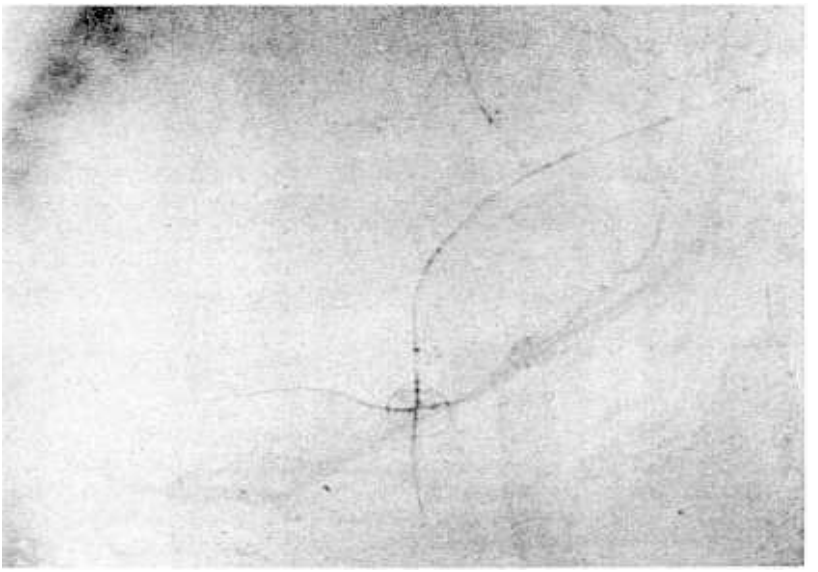

Figure 52-15: Cracks in substrate mirrored in surface topping.

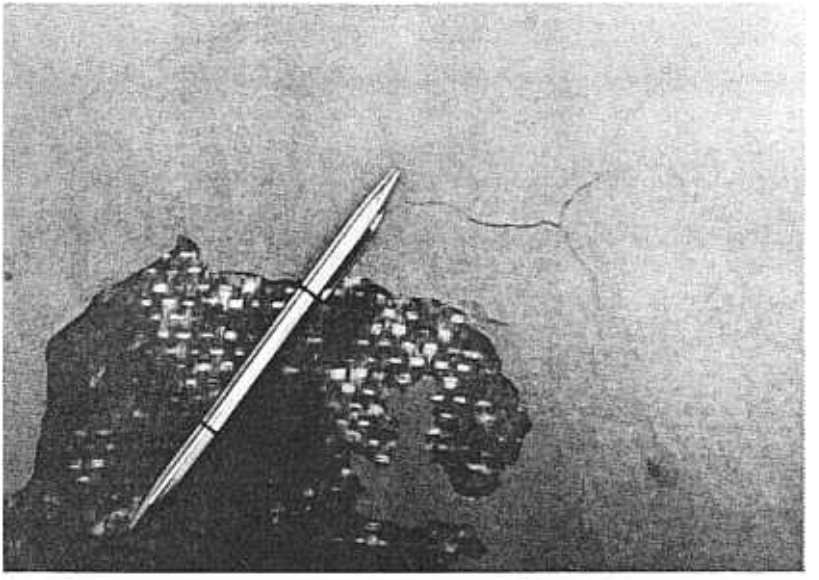

Figure 52-16: Use of too tightly woven, hard, reinforcing glass cloth, possibly with incorrect surface treatment. The resin in the surfacing has failed to wet it, causing delamination, then cracking due to cure shrinkage.

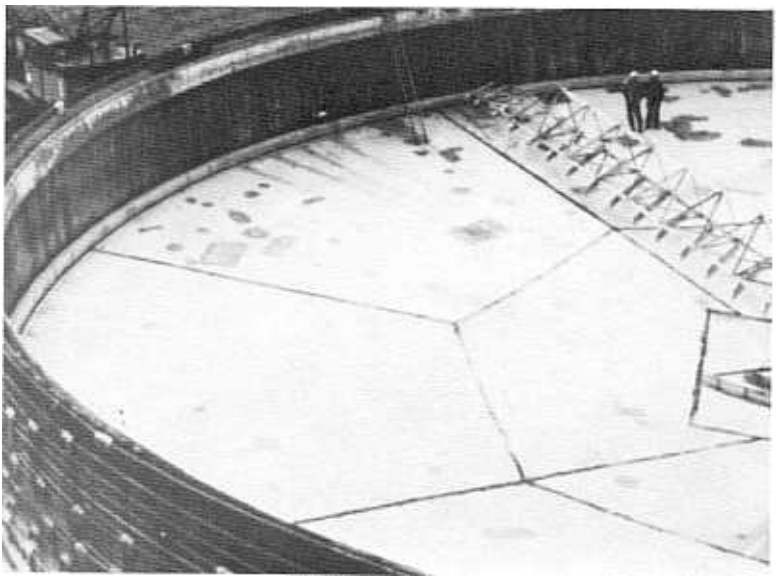

Figure 52-17: Mal-design of concrete floor in thicker bottom. Note areas where expansion joints merge at small, acute angles. It is very difficult to create or maintain such joints, and the surfacing over such pointed areas.

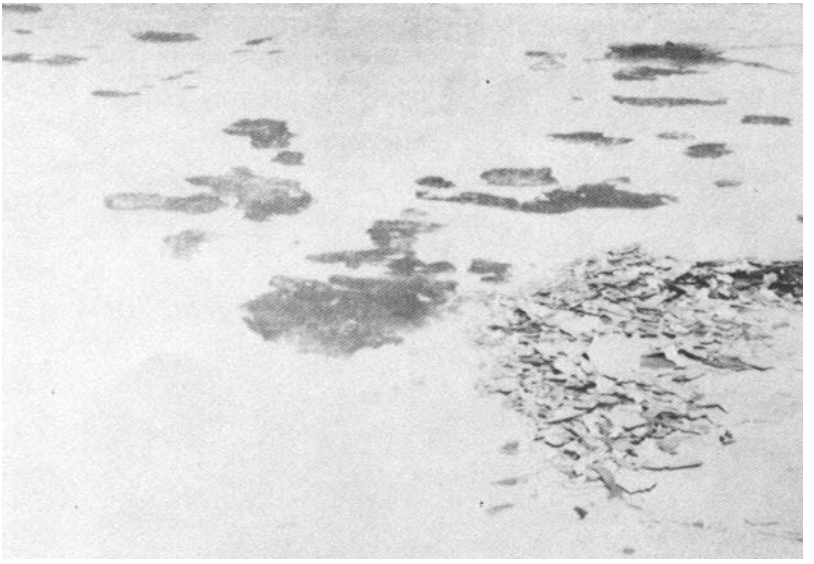

Figure 52-18: Close up of same concrete floor. Cure was inhibited by subsurface water drawn upward under topping, shortly after application, by big thermal changes, night to day, causing poor cure, delamination and cracking up.

BIBLIOGRAPHY

1. Sheppard, Walter Lee, Jr., *Chemically Resistant Masonry,* 2nd Ed, Marcel Dekker, NY (1982).
2. Sheppard, Walter Lee, Jr., Inspecting chemically resistant masonry, *Plant Engineering,* (March 19 and April 16, 1981).
3. Sheppard, Walter Lee, Jr., Spotting and avoiding problems with acid-resistant brick, *Chemical Engineering* (May 3, 1982).
4. Sheppard, Walter Lee, Jr., Failure analysis of chemically resistant monolithic surfacings:, *Chemical Engineering* (June 1984).
5. Sheppard, Walter Lee, Jr., Obtaining sound chemically resistant masonry, *The Construction Specifier* (December 1981 and March 1982).
6. Sheppard, Walter Lee, Jr., Trouble shooting chemically resistant masonry, *Civil Engineering,* pp 68-71 (May 1982).
7. Sheppard, Walter Lee, Jr., Expansion joints for chemically resistant masonry, *Chemical Engineering,* pp 79-81 (August 19, 1985).